NASA/TM–2004–213144

Air Quality Monitoring Report: A Review of Responses to the NASA Request for Information on Trace Contaminant Monitoring

Sponsored by NASA through joint support from the International Space Station Program Office (Code M), Advanced Human Support Technology (Code U), and the JSC Toxicology Group

South Shore Harbour Resort and Conference Center
Houston, Texas
October 21-22, 2003

July 2004

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Contents

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Acronyms

AHST	Advanced Human Support Technology
ANITA	analyzing interferometer for ambient air
BETX	benzene, toluene, ethyl benzene, and xylene
COTS	commercial off-the-shelf
DiDD	direct ionization discharge detector
ECLSS	environmental control and life support system
ESTEC	European Space Research and Technology Center
FID	flame ionization detector
FTIR	Fourier transform infrared
GC	gas chromatography
IMS	ion mobility spectrometry
ISS	International Space Station
LN_2	liquid nitrogen
MS	mass spectrometry
N_2	nitrogen
ORU	orbital replaceable unit
PID	photo ionization detector
ppm	parts per million
RFI	request for information
TCD	thermal conductivity detector
VOA	volatile organic analyzer
VOC	volatile organic compound

Executive Summary

Introduction

The ability to monitor the atmosphere of the International Space Station (ISS) is crucial to managing health risks and, ultimately, to mission success. Air monitoring in the space environment poses numerous technical challenges above and beyond those that are related to ground-based systems. Addressing these challenges is not new to NASA; NASA has significant experience with spacecraft air pollutant monitoring and several previous studies have evaluated the strengths and weaknesses of various approaches to air monitoring. However, given technological advancements, it is important to build upon lessons learned and to continue to seek out new approaches that can improve our ability to assess spacecraft habitability.

To achieve this, a Request for Information (RFI) for the ISS On-Board Environmental Monitoring Systems was released by NASA on August 9, 2003, with cooperative support provided by the ISS Program Office, Advanced Human Support Technology Group, and Toxicology Group at the Johnson Space Center. The purpose of the RFI was to identify next-generation environmental monitoring systems with demonstrated ability or potential to meet defined requirements for systems to evaluate air and water quality on board the ISS. This report summarizes the submission and analysis of proposed solutions designed to improve on the functionality of the existing volatile organic analyzer (VOA). The VOA is responsible for analysis of a wide range of volatile organic compounds that may be present in the ISS atmosphere. Experience with the existing VOA on ISS encompasses both success and failures, and NASA is using the RFI process to investigate new technologies that may improve upon existing capabilities. Ideally, a replacement for the VOA would be deployed in conjunction with the delivery of the Node 3 regenerative environmental control and life support system (ECLSS) currently scheduled for delivery to the Station in November 2007.

Summary of Requirements

Proposed systems and component technologies were developed to meet several technical requirements in addition to a prioritized set of goals to be considered as potential solutions. A brief summary of these is provided below.

Technical Requirements – The replacement system should:

- Fit within the current VOA footprint within the crew health care system rack.
- Detect and quantify a major percentage of targeted air contaminants.
- Operate in a spacecraft environment in a possibly highly contaminated atmosphere.
- Demonstrate acceptable instrument characteristics for linearity, rapid analysis time, rapid analysis cycle time, and low mass, volume, and power requirements.
- Demonstrate required instrument maintenance properties, including infrequent calibration and maintenance intervals and minimal use of resources.

Review Panel Approach

NASA received 10 submittals in response to the air portion of the RFI. A 16-member air quality review panel consisting of eight external air quality experts and eight NASA relevancy experts

(ISS Office, ECLSS, Toxicology) met on October 21 and 22, 2003, to review and score the air-only and air portion of the combined air-water system submittals. Presentations made by representatives of each entity that submitted a response to the RFI were followed by a question-and-answer session and panel deliberation. Scoring was accomplished through the use of technology assessment metric sheets (see Appendix) that enabled the rating of many specific aspects of each technology on a four-point system. Individual characteristics and/or system requirements were grouped and scored using the following topic areas of the scoring metric:

- Operation in a spacecraft environment
- Instrument characteristics
- System characteristics
- Compounds
- Instrument maintainability

Scores were given for both "demonstrated" and "potential" system performance wherever possible. One of the 10 proposed systems was reviewed but was not given a quantitative score for either category because the submitter was unable to attend the meeting and there was no supporting information.

Results

The following table presents the individual parameter and final total combined scores for each presenter/vendor who submitted a package in response to the RFI (only demonstrated system performance was considered in scoring). Although efforts were made to be as discriminating as possible in the scoring, a small difference in scores for any two vendors does not necessarily mean that one system is clearly superior to the other.

Vendor	ESTEC	Bruker	Space Dynam	JPL-House.	Star Instr.	JPL-Chut	Boeing	Smiths Detec.	OI Analy.
Operation in Spacecraft Environment	14.0	12	*	13.0	13.5	13.5	13.5	15.0	*
Instrument Characteristics	15.5	21	*	19.0	20.0	23.0	15.5	19.0	*
System Characteristics	13.0	10	*	11.0	10.0	9.5	10.5	11.5	*
Compounds *(double weighting)*	18.5	13	*	17.5	16.5	17.0	17.5	18.0	*
Instrument Maintainability	12.0	8	*	8.5	8.0	9.5	8.5	10.0	*
Combined Final Score	**91.5**	**77**	*****	**86.5**	**84.5**	**89.5**	**83.0**	**91.5**	*****

*Although scores for technology potential were given, panelists did not feel that sufficient information was available to provide a demonstrated score.

Conclusions

- It is difficult for any single monitoring system to excel in all five parameter areas as specified by NASA, and it may be necessary for NASA to prioritize requirements to fit a new system into available resources and schedule. Each system has individual strengths and weaknesses that must be critically evaluated in developing the next generation of ISS air monitoring. Given the range of compounds potentially present in the spacecraft environment, required detection limits, the remoteness of the monitoring, and limitations on system design and support, air monitoring in the ISS environment is extremely challenging.

- The wide range of chemical classes represented on the NASA priority lists, along with their required detection limits, posed difficulties for most of the systems. This conclusion generally held across all proposed technologies, although some technologies performed better than others in terms of achieving required detection limits. As might be expected, the bigger and more complex systems generally had greater capabilities.

- A wide variety of detectors and technologies was proposed in response to the NASA RFI. While some analytical techniques had critical weaknesses that might limit their ability to provide a comprehensive solution, it should be noted that no specific technology was identified as clearly superior for ISS purposes. In fact, the two highest scoring systems used very different analytical technologies, with the European Space Research and Technology Center (ESTEC) Fourier transform infrared technology and the gas chromatography/ion mobility spectrometry system proposed by Smiths Detection offering specific advantages and disadvantages. This observation is positive in that it does not appear that a "single path" exists that might limit technologies that can be used in designing the next generation of ISS air monitoring. Given uncertainties and limitations, it may be prudent for NASA to pursue at least two different technologies in the first phase of testing for any VOA replacement.

- Since final scoring was only based on "demonstrated" parameter scores, a distinguishing factor among proposed systems was the ability of presenters to actually demonstrate that their systems can achieve NASA requirements. Some proposed systems were still early in development and, therefore, lacked real data on required compounds or the structural and functional demands of the system. Some of the systems may still hold long-term promise, even though more development is needed.

- System design that evidences an appreciation for the difficulties of monitoring in a space environment was another distinguishing factor. Some presenters clearly understood the challenges of ISS monitoring and integrated those considerations into their system design. However, some presented system elements (e.g., size, power requirements) did not anticipate the practical demands of monitoring on board the ISS.

- The panel, in recognizing the benefits of drawing from individual strengths, envisions that the next generation of air monitoring on board the ISS might include a synthesis of several of the proposed systems. Regardless of the final combined score, the panel found areas of technical ingenuity in each of the presentations – with some of the systems complementing each other especially in terms of offsetting strengths and weaknesses. This type of system integration may ultimately best address the challenges facing NASA in improving air monitoring capabilities on board the ISS.

List of Air Quality Review Panel Members

Voting Panelists

PANEL CHAIR	John James Lyndon B. Johnson Space Center National Aeronautics and Space Administration
EXTERNAL SUBJECT MATTER EXPERTS	David Atkinson Pacific Northwest National Laboratory
	Christopher Gresham Sandia National Laboratory
	Robert Hughes Sandia National Laboratory
	Charles Kolb Aerodyne Research, Inc.
	Patrick McCann School of Electrical and Computer Engineering University of Oklahoma
	Kent Pfeifer Sandia National Laboratory
	Jeffrey Wyatt Office of Naval Research
	Sheng Yao Delphi Automotive Systems
NASA PANEL PARTICIPANTS	Tom Limero Wyle Laboratories Life Sciences Systems and Services
	John Graf Lyndon B. Johnson Space Center National Aeronautics and Space Administration
	Jay Perry George C. Marshall Space Flight Center National Aeronautics and Space Administration
	Jonette Stecklein Lyndon B. Johnson Space Center National Aeronautics and Space Administration

John Feighery
Lyndon B. Johnson Space Center
National Aeronautics and Space Administration

Gary Priest
Lyndon B. Johnson Space Center
National Aeronautics and Space Administration

Michael Barratt
Lyndon B. Johnson Space Center
National Aeronautics and Space Administration

Observers	Darrell Jan Mark Jernigan Jitendra Joshi John Park Don Pettit Ellen Baker John Trowbridge Torin McCoy Mike Barrett
TIA	Duncan Atchison Julianna Fishman Greg Defouw

Agenda for Air Quality Review Panel and
Listing of Presenting Vendors

Presentation Schedule for Air-Only Instruments – October 21, 2003

Panel Orientation
8:30 AM – 9:25 AM Salon E

Microsensor Systems (No presentation)
9:30 AM – 10:00 AM Panel Discussion and Deliberation

ESTEC (Videoconference)
10:00 AM – 10:45 AM Presentation
10:45 AM – 11:00 AM Question and Answer
11:00 AM – 11:30 AM Deliberation

Lunch
11:45 AM – 12:55 PM

Bruker Daltonics
1:00 PM – 1:45 PM Presentation
1:45 PM – 2:00 PM Question and Answer
2:00 PM – 2:30 PM Deliberation

Space Dynamics
2:30 PM – 3:15 PM Presentation
3:15 PM – 3:30 PM Question and Answer
3:30 PM – 4:00 PM Deliberation

JPL-Houseman
4:00 PM - 4:45 PM Presentation
4:45 PM – 5:00 PM Question and Answer
5:00 PM - 5:30 PM Deliberation

Panel Discussion
5:30 PM – 6:00 PM

Presentation Schedule for Combined Air-Water Instruments – October 22, 2003

StarVOC

8:00 AM – 8:45 AM	Presentation
8:45 AM – 9:00 AM	Question and Answer
9:00 AM – 9:30 AM	Panel Deliberation

JPL/Chutjian

9:30 AM – 10:15 AM	Presentation
10:15 AM – 10:30 AM	Question and Answer
10:30 AM – 11:00 AM	Deliberation

Boeing Team

11:00 AM – 11:45 AM	Presentation
11:45 AM – 12:00 N	Question and Answer
12:00 N – 12:30 PM	Deliberation

Lunch

12:30 PM – 1:45 PM

Smiths Detection

1:55 PM – 2:40 PM	Presentation
2:40 PM – 2:55 PM	Question and Answer
2:55 PM – 3:25 PM	Deliberation

OI Analytical

3:30 PM – 4:15 PM	Presentation
4:15 PM – 4:30 PM	Question and Answer
4:30 PM – 5:00 PM	Deliberation

Panel Discussion

1. Introduction

Monitoring of air pollutants is critical to ensuring the health of the crew on board the International Space Station (ISS) and, ultimately, to mission success. However, monitoring the ISS atmosphere poses numerous technical challenges, including hardware size limitations, restrictions on use of potentially hazardous reagents/carriers, microgravity considerations, the overall remoteness of the monitoring operations, and other factors unique to the spacecraft environment.

NASA has significant experience in addressing these air monitoring challenges and has been very active in evaluating the state-of-the-science to ensure that the best available technical resources are being used to monitor air in spacecraft. Over the past several decades, NASA has conducted or commissioned several studies designed to evaluate emerging technologies that might be used to improve spacecraft air monitoring capabilities. These include

- 1986 "Evaluation of Approaches to Space Based Environmental Monitoring" (prepared by Lockheed)
- 1992 "Spacecraft Trace Contaminant Monitor (TCM) Evaluation of Concepts" (prepared by McDonnell Douglas, ADL reference no. 67681)
- 1998 "Expert Panel Review of Analytical Technologies Suitable for a Second-Generation Air Quality Instrument for the International Space Station" (JSC 28254).

These evaluations highlighted the challenges posed by spacecraft monitoring, the strengths and weaknesses of proposed technologies, and the tradeoffs that are often required when developing a suitable air monitoring system. Although each of the evaluations provided useful information, the rate of technological advancement together with new experiences and challenges on board the ISS require that NASA continues to seek out new approaches and/or advancements in air monitoring. This necessity is heightened as NASA considers longer duration missions on the ISS and crewed missions to the Moon, Mars, and beyond.

Commensurate with these efforts, the ISS Program Office, Advanced Human Support Technology, and Toxicology Group at NASA Johnson Space Center released a Request for Information (RFI) on August 9, 2003. The purpose of the RFI was to seek out new technologies and solutions that can address these technical challenges and help in providing the next generation of air analysis on board the ISS. NASA currently has a volatile organics analyzer (VOA) on board the ISS that is designed to characterize ISS air quality with respect to a relatively broad range of targeted volatile organic compounds (VOCs). NASA hopes to build on existing air monitoring capabilities and provide an improved tool for reliably characterizing the habitability of the ISS environment. The RFI described the on-board VOA and provided information on certain system requirements that should be anticipated by vendors interested in responding to the RFI. These requirements include:

- Fitting within the current VOA footprint in the crew health care system rack
- Detecting and quantifying a significant percentage of identified compounds of concern
- Operating within a spacecraft environment in a possibly contaminated atmosphere

- Specified instrument characteristics (e.g., linearity, analysis time)
- Desirable instrument maintenance properties (e.g., required calibration intervals)

The RFI also described the following four prioritized goals for the development of a VOA replacement system:

1. Elimination or reduction of the use of hazardous substances
2. Reduction in logistics costs
3. Improved contaminant detection and quantification
4. Volume and mass properties reductions into a $33.5 \times 19 \times 10.5$ in. footprint

A particular focus of the RFI was the listing of specific air pollutants prioritized into three categories along with targeted minimum detection limits (Table 1). It is important to recognize that although a proposed system may be able to demonstrate these detection limits in a controlled setting, the complexity of monitoring in the ISS environment may result in poorer system performance than anticipated.

Table 1. Targeted Compounds for Air Quality Monitoring Specified in the RFI

Compounds	Minimum Detection Limit
Priority 1	
Ethanol	10.0 parts per million (ppm)
Acetaldehyde	0.1 ppm
Acetone	1.0 ppm
Dichloromethane	0.03 ppm
Formaldehyde	0.01 ppm
Ammonia	1.0 ppm
Methanol	0.2 ppm
Octamethylcyclotetrasiloxane	0.05 ppm
Hexamethylcyclotrisiloxane	0.1 ppm
Propylene glycol	0.5 ppm
Perfluoropropane	10.0 ppm
Priority 2	
1-Butanol	0.5 ppm
2-Ethoxyethanol	0.1 ppm
Benzene	0.01 ppm
Acrolein	0.01 ppm
C5-C7 Alkanes	2.0 ppm
Decamethylcyclopentasiloxane	0.1 ppm
C3-C8 aliphatic sat. aldehyde	0.1 ppm
Ethyl benzene	1.0 ppm
2-Propanol	3.0 ppm
Ethylene (plants)	0.05 ppm
Freon 113	2.0 ppm

Compounds	Minimum Detection Limit
Furan	0.01 ppm
Toluene	1.0 ppm
Xylenes	2.0 ppm
Priority 3	
1,2-dichloroethane	0.01 ppm
Alkyl amines	0.5 ppm
4-Methyl-2-pentanone	2.0 ppm
Carbonyl Sulfide	0.01 ppm
Chloroform	0.02 ppm
Diacetone Alcohol	0.2 ppm
Freon 11	2.0 ppm
Freon 12	2.0 ppm
Isoprene	0.05 ppm
Limonene	1.0 ppm
Trimethylsilanol	0.5 ppm
Vinyl Chloride	0.05 ppm

NASA, in response to the RFI, received 10 submission packets that addressed air monitoring (either air only or combined air-water systems). In October 2003, a 16-member panel of subject matter experts was assembled to review information submitted in response to this RFI. Half of the panelists were external to NASA, while the remainder represented internal NASA experts from several different program areas (e.g., Environmental Control and Life Support System, Toxicology). This air quality review panel was asked to provide critical review and feedback to NASA on the merits of the proposed air monitoring systems. This document is intended to describe the methodology applied by the panel in its analysis and to present the panel results and recommendations. It should be noted that a similar panel was convened to address water monitoring on board the ISS, as this was also a focus of the RFI. Although some presenters responded to the RFI with joint air and water monitoring proposals, the discussion presented in this document is specific to the air sections of any joint proposal.

2. Structure of the Panel Review

The charge to the panel was to examine presently available technologies and to rate those technologies in terms of their ability to meet requirements and prioritized goals for the next-generation analyzer on board the ISS. As requested in the RFI, the presenters of each technology provided abstracts or other preliminary information before the meeting. This information was distributed and evaluated by the panelists prior to their convening on October 21-22, 2003.

The meeting began with an overview of the status of air monitoring on board the ISS and the NASA considerations and/or requirements that are pertinent to air monitoring. Subsequently, the responding vendors were each given approximately 45 minutes to describe their proposed monitoring system. At the end of each presentation, panelists asked for additional information or necessary clarification on the proposal. If a panel member has or had a strong commercial relationship with a vendor, that panel member was excused from both the question-and-answer session and the panel deliberation for that particular vendor.

2.1 Summary of Scoring Approach

Panelists scored the concept using a technology assessment metric (see Appendix). This metric was a modified version of the tool used in the 1998 panel review of spacecraft air quality instrumentation. This 1998 tool, in turn, was based on the preliminary metric proposed in the Advanced Environmental Monitoring and Control Program document "Technology Development Requirements" (JPL-D-13832). Thus, this scoring system has been successfully used in previous NASA efforts.

Each concept was scored based on consideration of specific system characteristics falling under the general parameters of (1) operations in spacecraft environment, (2) instrument characteristics, (3) system characteristics, (4) compounds, and (5) instrument maintainability. Several specific attributes are described under each of these parameters. For example, for the "system characteristics" parameter, four attributes are listed ("maturity," "resources," "environmental impact," and "complexity"). Refer to Table 2 for a complete listing of all attributes evaluated. Specific mission requirements were provided for some of the most critical attributes to facilitate scoring. These included requirements to operate within defined temperature and pressure ranges, limitations on the mass, volume, and power of any proposed system, and other important considerations for spacecraft monitoring.

Scores were summed across each individual attribute to arrive at the final parameter score. Each of the five parameter scores was weighted equally, with the exception of the "compounds" parameter, which received double weighting because of its importance. For each vendor, two categories of scores – "demonstrated" (D) and "potential" (P) – were given by the panelists. The "potential" category is fundamentally a panelist assessment of what the proposed system might reasonably be able to achieve, albeit with certain conditions and/or modifications. Only the "demonstrated" scores were used in determining final system scores given the subjectivity inherent in the "potential" scoring.

3. Results of the Evaluation

All individual panel scores for both the demonstrated and potential categories are presented in Table 2. The table is organized in the order in which the presentations appeared on the panel agenda. Please note that only nine presenters/vendors appear on this table, although a total of 10 responses to the RFI were received. This is because one responder (Microsensor Systems) was unable to give a presentation, and their submission was not considered to be adequately comprehensive to support quantitative scoring (although it was reviewed qualitatively and is addressed in the discussion section of this document). The presence of a "?" as an entry indicates that the panel did not feel it had enough information to estimate the potential ability of the proposed system for that particular characteristic. Also, note that "demonstrated" scores were not recorded for several presenters. Although there was merit to these proposed systems, panelists did not feel that enough information was provided to allow for a quantitative "demonstrated" scoring that could be fairly compared with the other presenters/vendors. All individual scores were summed based on the weighting procedure described previously; these are presented in Table 3. In the Appendix, individual technology assessment metrics specific to each presenter/

vendor are presented. All individual scores, along with applicable panelist comments, are included in these assessment sheets.

Table 2. Summary of Ratings by the Air Quality Review Panel

Presenter/Vendor	**Estec**		**Bruker**		**Space Dynam**		**JPL/ HOUSE**		**Star**		**JPL/ CHUTJ**		**Boeing**		**Smith Detect**		**OI Analytic**	
Analytical Methodology	**FTIR**		**GC-GDA**		**FTIR-GC**		**GC-MS mag sec**		**GC-GC (DiDD)**		**GC-MS Paul trp**		**Multiple**		**GC^2-IMS^2**		**Multisor bGC**	
	D	**P**	**D**	**P**	**D**	**P**	**D**	**P**	**D**	**P**	**D**	**P**	**D**	**P**	**D**	**P**	**D**	**P**
Operation in Spacecraft Environ.																		
Temperature	4.0	4.0	4.0	4.0		4.0	3.0	3.0	4.0	4.0	3.0	3.0	3.0	3.0	4.0	4.0		4.0
Pressure	4.0	4.0	4.0	4.0		4.0	4.0	4.0	2.5	3.5	4.0	4.0	4.0	4.0	4.0	4.0		4.0
Humidity	4.0	4.0	3.0	4.0		3.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0		3.0
Microgravity compatible	---	---	---	---		---	---	---	---	---	---	---	---	---	----	---	---	---
Ability to perform in highly contaminated atmosphere	2.0	3.0	1.0	3.0		3.0	2.0	3.0	3.0	4.0	2.5	3.0	2.5	3.0	3.0	3.0		2.5
Instrument Characteristics																		
Quantitation range	2.0	3.0	2.0	3.0		3.0	2.0	3.0	2.0	4.0	3.0	3.0	3.0	3.5	2.0	3.0		?
Analysis time	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.5	4.0		4.0
Analytical cycle time	4.0	4.0	4.0	4.0		4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0		4.0
Mass	2.0	3.0	4.0	4.0		2.5	3.0	4.0	4.0	4.0	4.0	4.0	2.0	3.5	3.0	4.0		3.0
Volume	1.5	2.0	3.0	4.0		2.5	2.0	3.0	3.0	4.0	4.0	4.0	1.5	3.0	3.0	4.0		3.0
Power	2.0	4.0	4.0	4.0		2.5	4.0	4.0	3.0	4.0	4.0	4.0	1.0	3.0	3.5	4.0		2.5
System Characteristics																		
Maturity including software	3.5	3.5	2.0	3.0		?	2.0	3.0	2.5	4.0	2.5	3.5	2.5	3.0	3.0	4.0		4.0
Resources	4.0	4.0	3.0	3.0		3.0	3.0	3.0	2.5	3.0	2.5	3.0	2.5	3.0	3.0	3.0		2.0
Environmental impact	3.0	3.0	3.0	3.0		3.0	3.0	3.0	2.5	3.0	2.0	3.0	3.0	3.0	3.0	3.0		3.0
Complexity	2.5	2.5	2.0	2.0		1.0	3.0	3.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5		1.5

Presenter/Vendor	Estec		Bruker		Space Dynam		JPL/ HOUSE		Star		JPL/ CHUTJ		Boeing		Smith Detect		OI Analytic	
Compounds																		
% Detectable Cat 1 compounds at specified limit	2.5	3.0	2.5	3.0		3.0	2.5	3.0	2.5	3.0	2.5	2.5	2.5	3.5	3.0	3.0		3.5
% Detectable Cat 2 and 3 compounds at specified limit	3.0	3.0	2.5	3.0		3.0	3.0	3.0	3.0	3.5	3.5	4.0	3.5	4.0	3.5	3.5		3.5
Specificity in spacecraft atmosphere – Cat 1	2.5	3.0	2.5	3.0		3.0	3.0	3.0	2.5	3.5	2.5	3.0	2.5	3.5	3.0	3.0		3.5
Specificity in spacecraft atmosphere – Cat 2 and 3	2.5	3.0	2.5	3.0		3.0	3.0	3.0	2.5	3.5	2.5	3.0	3.0	4.0	3.5	3.5		3.5
Accuracy (6 mo)	4.0	4.0	2.0	2.5		3.0	3.0	4.0	3.0	4.0	3.0	4.0	3.0	4.0	2.5	3.5		4.0
Precision (over 1 month operation)	4.0	4.0	1.0	2.5		3.0	3.0	4.0	3.0	4.0	3.0	4.0	3.0	3.0	3.0	4.0		4.0
Instrument Maintainability																		
Calibration interval (quantitative purposes)	4.0	4.0	1.0	2.0		3.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	3.0	3.0	3.5		2.0
Maintenance interval: minor - major	4.0	4.0	3.0	3.0		3.0	3.0	3.0	2.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0		2.0
ORUs and supplies	4.0	4.0	4.0	4.0		4.0	3.0	3.5	3.0	4.0	4.0	4.0	3.0	3.0	4.0	4.0		4.0

Table 3. Summary of Demonstrated Parameter Scores and Total Vendor Scores

Vendor	ESTEC	Bruker	Space Dynamics	JPL-Houseman	Star Instr.	JPL-Chutjian	Boeing	Smiths Detection	OI Analytical
Operation in Spacecraft Environment	14.0	12.0	*	13.0	13.5	13.5	13.5	15.0	*
Instrument Characteristics	15.5	21.0	*	19.0	20.0	23.0	15.5	19.0	*
System Characteristics	13.0	10.0	*	11.0	10.0	9.5	10.5	11.5	*
Compounds *(Double Weighting)*	18.5	13.0	*	17.5	16.5	17.0	17.5	18.0	*
Instrument Maintainability	12.0	8.0	*	8.5	8.0	9.5	8.5	10.0	*
Combined Final Score	**91.5**	**77.0**	*****	**86.5**	**84.5**	**89.5**	**83.0**	**91.5**	*****

*Although scores for technology potential were given, panelists did not feel that sufficient information was available to provide a demonstrated score.

4. Discussion of Scores

While efforts were made to be as discriminating as possible in assigning individual scores, it is important to note that the scoring is semi-quantitative. Therefore, the presence of a slight difference between final scores for any two systems does not indicate that one system is clearly superior to the other. When further examining the results of the panel analysis, it is reasonable to group the systems by the two main proposed technologies: (1) Fourier transform infrared (FTIR) technology and (2) gas chromatography (GC) used in conjunction with specialized detectors such as ion mobility spectrometry (IMS) or mass spectrometry (MS). Results of this panel analysis did not suggest that any one particular technology is best suited for application on board the ISS. It is worth noting that the top two scores presented in Table 3 (tie scores of 91.5 by the European Space Technology Center (ESTEC) and Smiths Detection) were assigned to two proposed systems based on very different analytical methodologies. Among proposed systems there clearly were trade-offs between size, complexity, performance, and cost. Accordingly, a more specific discussion of the strengths and weaknesses of each proposed system is provided below, followed by a general comparison of the proposed systems as grouped by analytical technologies.

4.1 Individual System Summaries (presented in order by score)

4.1.1 ESTEC

The ESTEC system, which uses FTIR technology within its ANITA (analyzing interferometer for ambient air) monitoring device, is composed of commercially available parts but was specifically engineered to make it compatible with spacecraft requirements. Accordingly, one of ESTEC's biggest strengths was the ability to clearly demonstrate system performance. This strength helped ESTEC across all five performance parameters. ESTEC scored high on "instrument maintainability," owing to the limited consumables, and infrequent maintenance and calibration requirements. High marks were also given for "system characteristics," despite concerns about the potential complexity of operating an FTIR on orbit. Demonstrated accuracy and precision also resulted in a high score for "compounds," even given ESTEC's inability to sufficiently detect formaldehyde and benzene. Panelists' concern about excess mass, volume, and power requirements resulted in a low score for "instrument characteristics." There was also some concern about how well an FTIR would perform in a highly contaminated environment (i.e., background interferences by coexisting gaseous species), especially after an emergency event such as a fire. Compensation for these concerns may be achieved through instrument calibration, filtering, and self-regulation, however. Additionally, there were questions about how well the system would address unknown compounds (additional targeted calibration models may be used to help deal with these concerns) and whether adequate quantification at the low end of the range could be achieved without limiting the range of compounds that can be detected.

4.1.2 Smiths Detection

The Smiths Detection system features dual GC columns, each connected to IMS and thermal conductivity detectors (TCDs). Panelists ranked the system highly on "instrument characteristics" based on considerations of mass, volume, and power requirements. The Smiths Detection system also was considered well suited to the spacecraft environment and was the highest ranked vendor for this parameter, which included considerations for performance in a contaminated atmosphere. The system was ranked almost as high as the ESTEC FTIR for the "compounds" parameter (despite potential difficulties in detecting vinyl chloride, formaldehyde, and perfluoropropane with the IMS), and it benefited from being able to detect siloxanes while many other vendors could not. Panelists were also impressed with the overall redundancy of the system. A relatively low score for demonstrated system accuracy was due to a potential analytical gap between the IMS and TCD detection ranges. Precision was also questioned, especially at the edges of the range.

4.1.3 JPL-Chutjian

JPL-Chutjian's proposed system, a miniaturized GC with a Paul Ion Trap MS, also received high scores. As it seemed to have clearly addressed spacecraft limitations for mass, power, volume, and other factors, panelists scored this system highest among the vendors with respect to "instrument characteristics." Although the system was expected to have problems detecting ammonia and formaldehyde, the same is true of most of the systems reviewed. Panelists felt that the JPL-Chutjian system would have less cross-mass interferences than the other GC/MS systems they evaluated. A low score in "system characteristics" was due to concerns about the potential impacts resulting from the use of helium and benzene, toluene, ethyl benzene, and xylene (BTEX) in the spacecraft environment as well as the resource consumption needs for system operation. Concerns were also expressed about reliability issues with the turbo molecular pump (e.g., potential overheating). The potential for overloading the trap was also recognized as a limitation that will be found in most MS systems.

4.1.4 JPL-Houseman

JPL-Houseman also proposed a miniaturized GC/MS, but with a Faraday cup detector array and a charge-coupled device as detectors. This system had many of the strengths and weaknesses typical of a GC/MS system. It was given relatively high scores for the "compounds" parameter. This system received lower scores for "instrument characteristics," largely because of its higher mass and volume requirements. Panelists also felt that system maturity (particularly the detector configuration) was an unaddressed concern. The panel recognized the possibility of saving on carrier gas needs by operating the GC only when the mass spectrum indicates a change from baseline as a proposed area of promise.

4.1.5 Star Instruments Inc.

Star Instruments proposed a dual GC system that currently is applied in conjunction with a flame ionization detector (FID). Panelists generally felt that Star demonstrated good depth of knowledge about the uniqueness of monitoring in a space environment. The proposed system received a relatively high score in terms of "operation in spacecraft environment," as panelists felt the small pre-concentrator would allow for reasonable cleanup in the event the spacecraft environment was highly contaminated. There was some concern expressed, however, regarding pressure differences and their effect on the detectors, especially the ability of the system to be effectively calibrated for compounds of interest (the differential pressure sensors of the microFAST GC may help to minimize these effects). The dual GC system was viewed as one of the most robust GC systems presented to the panel, and scored well on demonstrated "instrument characteristics." Moderate scores were given for "system characteristics" because of some lack of demonstrated system maturity, the relative complexity of the system, and possible ISS incompatibilities with the proposed use of argon in one detector (although other detector options are available). There was also concern expressed by panelists about what changes to the system (e.g., detector selection, power requirements) would be necessary to enable it to adequately quantify target compounds. For example, an FID cannot be used on the ISS, so successful use of an alternate detector would need to be demonstrated. Also, concern affected the "demonstrated" accuracy and precision scores, which resulted in a low parameter score. Scoring for "instrument maintainability" was also slightly lower given unknowns associated with instrument calibration and maintenance intervals, although the GC instrument design may help to mitigate concerns.

4.1.6 Boeing

At the request of Boeing, no description or discussion of its proposed system is being included in this report.

4.1.7 Bruker Daltonics

Bruker Daltonics proposed a somewhat novel system, which used GDA, metal oxide and electrochemical sensors, photo ionization detector (PID), and IMS following GC separation. The proposed system scored very high on the "instrument characteristics" parameter, owing to its excellent mass, power, and volume requirements. However, there were significant concerns regarding the analytical capabilities of the system, especially in a highly contaminated spacecraft environment. The perception of this system was that it would perform well as an "alarm technology," but it would have difficulty accurately identifying and quantifying many target compounds for the ISS. Unknowns would present another problem for this system, although the variety of proposed detectors may improve capabilities. Considering that accuracy and precision were also not demonstrated, the Bruker system received relatively low scores for the "compounds" parameter. While panelists agreed many aspects of the system had technical merit, the majority opinion was that it lacked maturity. Consideration for overall system complexity and the potential for maintenance difficulties (e.g., due to multiple filters, windows, membranes) also reduced scores. Some panelists commented that it appeared that a substantial amount of data from the IMS was not being used in the proposed system, while other panelists expressed concern about how well the proposed trap and column would handle reactive air contaminants (e.g., aldehydes).

4.1.8 Space Dynamics

Uniquely among the presenters, Space Dynamics proposed a dual GC system (using photo thermal detectors), combined with a miniaturized FTIR real-time process monitor module. In reviewing this system, panelists felt uncomfortable providing quantitative "demonstrated" scores because the system as a whole is not developed to the point at which it can demonstrate performance. They therefore evaluated apparent strengths and weaknesses and provided scores based on system potential. Given the complexity of the system (close to 10 modules), there are questions as to whether a final combined system could meet ISS mass, power, and volume requirements. Although the vendor attempted to provide some quantitation ranges for the FTIR, overall system performance could not be assessed. While panelists could appreciate many of the strengths of this type of system design, this appreciation was mitigated by a number of questions about overall system performance (e.g., performance of the photo thermal detector system) that are unlikely to be addressed until the integrated system and software are fully developed.

4.1.9 OI-Analytical

OI-Analytical proposed a dual GC system that would take advantage of multiple columns and detectors in monitoring the ISS atmosphere. The panel, in an approach similar to that taken with the Space Dynamics proposal, decided that it was best to score the OI-Analytical system based on “potential” rather than “demonstrated” performance. The panel came to this conclusion partially because only FID performance was used to assess system capabilities, and this detector cannot be used on board ISS. Overall, the panel liked the redundancy built into the proposed system, and panel members gave the system high scores for the potential to adequately monitor Category 1, 2, and 3 compounds. The possibility of being able to characterize difficult compounds such as formaldehyde and ammonia was a positive aspect of the proposed system, although there was some concern about how well the system would perform with unknowns and/or in a highly contaminated spacecraft environment. Panelists felt that the complexity of the system might lead to frequent calibration or maintenance intervals as well. Additional questions raised by panelists included the potential power requirements and the system’s quantitation range for some compounds.

4.1.10 Microsensor Systems

The Microsensor Systems proposal focused on the use of largely commercial off-the-shelf (COTS) technologies. The company proposed a combination of systems, including a miniaturized handheld GC and electrochemical sensor, in responding to the RFI. After reviewing the submittal, panelists determined that it would not be appropriate to score the Microsensor System proposal. Because representatives from Microsensor Systems did not attend the panel meeting or provide a presentation, it was impossible for the panelists to seek clarification on critical issues. Overall, the panelists did not view the proposal as a comprehensive solution to the problem at hand. Panelists suggested that it may not be feasible to use cabin air as a carrier gas for the GC, and cautioned that the system would likely have trouble with light gases, high molecular weight compounds, and unknowns in the ISS atmosphere. The inability to question technical representatives from Microsensor Systems regarding column and detector selection, integration of the system, and achievable detection limits made scoring difficult. In summary, panelists had numerous questions and, based upon the available information, the proposed system did not seem to offer significant improvement over the existing VOA. This instrument falls in the “electronic nose” category; and it appears at this time that it (and others like it) would not be able to meet the stringent requirements set out in the RFI. However, it does offer the advantages of much smaller size and power requirements, and much lower cost than any of the other instruments.

4.2 Summary/Comparison of FTIR Techniques

Two RFI submissions – ESTEC and Space Dynamics – focused on the use of FTIR technology. Although the ESTEC unit is composed of commercially available parts (90% COTS, it was specifically built for detection of targeted VOCs in the spacecraft environment. High scores for this unit are reflected primarily in the areas of operations, instrument characteristics (analysis time, analytical cycle time), system characteristics (maturity, resources), compounds (accuracy, precision), and instrument maintainability. Areas of concern for this technology are the mass, volume, and power requirements of the instrument as well as its complexity. FTIR relies on a laser that has a lifetime of 3–5 years that would not allow in-flight replacement should a failure occur. The panel was also concerned that calibration and alignment of the moving mirror may be compromised after launch, and that certain compounds (i.e., siloxanes) might affect FTIR components. Detection and quantification of formaldehyde will be an issue for this system as well as for the GC systems that will be discussed later. The ratings for the FTIR-GC unit proposed by Space Dynamics are based on a concept potential only as demonstrated capabilities were not available. This unit was scored similarly in many of the same areas (potential only) as the ESTEC unit, but major concerns were raised about the complexity of this system, which may have as many as 10 different integrated modules.

4.3 Summary/Comparison of GC/MS/IMS Techniques

In the area of operations in a spacecraft environment (temperature, pressure, humidity), all of the systems were rated similarly (3–4) with the exception of a potential pressure issue with Star's proposed system. The ability of any of the proposed systems to perform in a highly contaminated environment is an issue that has scores spanning the range in the "demonstrated" (1–3) and "potential" (2.5–4) columns. Star scored the highest in this category as its system makes use of small, independent traps (sorbent tubes) that serve as a sampler and a barrier that protect the instrument. A contaminated trap can be replaced from supply if it cannot be cleaned.

Most of the proposed systems had difficulty in identifying and quantifying formaldehyde and ammonia, which reduced their "instrument characteristics" score (demonstrated 2–3). With only one exception (Smiths 3.5), all systems exceeded requirements for analysis time and analytical cycle time in both demonstrated and potential categories. On most accounts each of the systems either met or exceeded (3–4) mass, volume, and power requirements in their demonstrated systems with the exception of Boeing's system, which is significantly larger and draws more power than the other systems.

System characteristics are concerned with system maturity and complexity, resources, and environmental impact. Fairly mature systems and software packages were noted in several of the systems (Star, JPL/Chutjian, Boeing, Smiths). For Star, JPL/Chutjian, and Boeing, additional software may be needed depending on their selection of detectors. All systems will require a carrier gas (e.g., nitrogen (N_2),helium). In addition Star may need to use argon for its plasma detector, and discussions surrounding a system rupture concluded that releases of argon would not harm the crew or impact the physical plan of the ISS. JPL/Chutjian suggested a plan to use BTEX to calibrate the spectral range. BTEX is comprised of benzene and other potentially hazardous compounds that may pose an environmental issue if leaked. Across the board the level of complexity of all proposed systems scored in the 2–3 range (seven to three modules), with the exception of the potential system offered by OI Analytical, which was rated at 1.5.

All proposed and demonstrated technologies received scores of 2.5–3 (Smiths was the only 3) in their ability to detect 90% of Category 1 compounds with slight increases in score when considering their potential capabilities, with the exception of Boeing and OI Analytical, which both show more potential to exceed requirements in this area. Ability to detect 80% of Category 2 and 3 compounds was met by all demonstrated technologies with the exception of Bruker Daltonics and OI Analytical ("potential" score only). The requirement to specify 90% of Category 1 compounds was demonstrated by only two entities (JPL/Houseman and Smiths Detection), and the ability to meet the requirement of specifying 80% of Category 2 and 3 compounds was met and demonstrated by JPL/Houseman, Boeing, and Smiths Detection. Ratings for accuracy (six months) and precision (in excess of one month operation) for all systems meet or exceed requirements with the exception of Bruker Daltonics, which scored 2 and 1 respectively in these areas.

The instrument maintainability section is concerned with calibration and maintenance intervals, orbital replaceable units (ORUs), and supplies. The only demonstrated system to meet the requirement of a six-month calibration interval was Smiths Detection, followed by a Boeing system that may have potential to meet the requirement. All systems with the exception of Star met the requirements for instrument maintenance (minor – every six months; major > one year). Potential electronics-maintenance issues are anticipated with the Star system. All systems meet the requirements for ORUs and supplies of < 5 kg every six months.

5. Conclusions

- It is difficult for any single monitoring system to excel in all of the five parameter areas specified by NASA (operation in a spacecraft environment, instrument characteristics, system characteristics, compounds, and instrument maintainability). Given the range of compounds potentially present in the spacecraft environment, required detection limits, the remoteness of monitoring, and limitations on system design and support, air monitoring in the ISS environment is extremely challenging. As might be expected, trade-offs with each proposed system were apparent. For example, the downside of a proposed system that is capable of monitoring the broadest range of specified compounds may be excessive mass and power requirements, or concerns about system complexity and maintenance. Each system has individual strengths and weaknesses that must be critically evaluated in decisionmaking regarding the next generation of ISS air monitoring.

- The reactive mixture of many compounds on the NASA priority lists, along with the very low detection limits required for other compounds, posed severe challenges for most of the systems. This conclusion generally held across all proposed technologies, although some systems did perform better than others in terms of achieving required detection limits. Most systems seemed to be better able to meet NASA requirements for Category 2 and 3 compounds, largely due to difficulties experienced in analyzing ammonia and formaldehyde (Category 1 compounds).

- A wide variety of detectors and technologies was proposed in response to the NASA RFI. While some analytical techniques had critical weaknesses that might limit their ability to provide a comprehensive solution, it should be noted that no specific technology was identified as clearly superior for ISS purposes. In fact, the two highest scoring systems employed very different analytical technologies, with the ESTEC FTIR and the GC/IMS system proposed by Smiths Detection both offering particular advantages/disadvantages. This observation is positive, in that it does not appear that a “single path” exists that might limit technologies that can be used in designing the next generation of ISS air monitoring systems. Given uncertainty in system performance and capability, it may be prudent for NASA to pursue at least two separate technologies in the first phase of testing for any VOA replacement.

- Since final scoring was based only on “demonstrated” parameter scores, one of the distinguishing factors among proposed systems was the ability of the presenter to actually demonstrate that a system can achieve NASA requirements. Some proposed systems were yet immature or ague on details; these lacked real data on required compounds or the structural and functional demands of the system. Although the panel provided “potential” scores in most cases, there is much more uncertainty with these scores given the technical assumptions that had to be made by the scoring panel. It is important to note, however, that some of these proposed systems may be promising in the long term, even though a lack of demonstrated performance hurt them in this scoring.

- System design that evinces an appreciation for the difficulties of monitoring in a space environment was another distinguishing factor. Some presenters clearly understood the challenges of the ISS and integrated those considerations in their system design. However, some incorporated system elements (e.g., excessive power requirements) did not anticipate the practical demands of monitoring on board the ISS. Generally, the most successful vendors were those that had previously focused years of effort on the monitoring of spacecraft air contaminants. The experience of these vendors was evident, as they tended to have actual data and provided the most realistic assessments of how their systems would perform in the spacecraft environment.

- Recognizing the benefits of drawing from individual strengths, panelists envision that the next generation of air monitoring on board ISS might include a synthesis of several of the proposed systems. Regardless of the final combined score, the panel found areas of technical ingenuity in each of the presentations, with some of the systems complementing each other especially well in terms of off-setting strengths and weaknesses. This type of system integration may ultimately best address the challenges facing NASA in improving ISS air monitoring capabilities.

Appendix: Individual Technology Assessment Metric Scoring Sheets

Technology Assessment Metric for ESTEC
Air Quality Panel: ISS Environmental Monitoring
Request for Information

Requirements Scale (except where noted)
0 – requirement not met
1 – requirement not met, but meets 25–50% of requirement
2 – requirement not met, but meets in excess of 50% of requirement
3 – requirement met
4 – requirement exceeded

Parameter 1: Operation in Spacecraft Environment
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Temperature	65–85°F (18-29°C)		4	4
Pressure	10.2–15.0 psia		4	4
Humidity	5–95% R.H.		4	4
Microgravity compatible		**Absolute Requirement**	*	*
Ability to perform in highly contaminated atmospheres		? Ground-based support needed in the event of unexpected compounds or updated calibrations ? Questions about ability to identify unforeseen compounds ? Questions about how to filter dirty atmosphere	2	3
Total Score Parameter Score			14	15

***No score given for absolute requirement.**

Parameter 2: Instrument Characteristics
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Quantitation range	0.01–10 ppm	? Not tested at low end of concentration range ? Potential score based on use of cooled detector	2	3
Analysis time	< 1 hr		4	4
Analytical cycle time	< 1.5 hr		4	4
Mass	22 kg	Concern about heaviness of ANITA	2	3
Volume	1.2 ft^3 (0.034 m^3)		1.5	2
Power	< 100 W/150 W peak		2	4
Total Score			15.5	20

Parameter 3: System Characteristics
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Maturity (WF=2)	> 75% COTS	Always a model issue	3.5*	3.5*
Resources (WF=1)	1 + power & data		4**	4**
Environmental impact (WF = 1)	Contaminants not released to atmosp.		3***	3***
Complexity (WF =2)	< 5 modules (heaters, GCs, detectors, etc., pneumatics)		2.5****	2.5****
Total Score			13	13

*Maturity: 100% COTS = 4, 75% COTS = 3, 50% COTS = 2, 25% COTS = 1, < 25% COTS = 0
**Resources: 0 resources = 4, 1 resource = 3, 2 resources = 2, > 2 resources = 0, exotic resource (i.e., LN_2) = disqualified
***Env.: No products released = 3, products released/not harmful = 2, released products harmful to crew/systems = 0
****Complexity: < 3 modules = 4, < 5 modules = 3, < 8 modules = 2, < 10 modules = 1, > 10 modules = 0

Parameter 4: Compounds
Weighting factor = 2

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
% Detectable Cat 1 compounds at specified limit	90%		2.5	3
% Detectable Cat 2 and 3 compounds at specified limit	80%		3	3
Specificity in spacecraft atmosphere	90% of Category 1 compound list		2.5	3
Specificity in spacecraft atmosphere	80% of Category 2 compound list		2.5	3
Accuracy (6 mo.)	± 30–50%		4	4
Precision (over 1 mo. operation)	± 20%		4	4
Total Score			18.5	20

Parameter 5: Instrument Maintainability
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Calibration interval (quantitative purposes)	6 mo.		4	4
Maintenance interval: minor-major	Every 6 mo. > 1 yr		4	4
ORUs and supplies	Every 6 mo. < 5 kg		4*	4*
Total Score			12	12

*ORU/supplies: > 6 mo./< 3 kg = 4, 6 mo./< 5 kg = 3, 6 mo./> 5 kg = 2, < 6 mo./< 5 kg = 1, < 6 mo./> 5 kg = 0

Technology Assessment Metric for Smiths Detection
Air Quality Panel: ISS Environmental Monitoring
Request for Information

Requirements Scale (except where noted)
0 – requirement not met
1 – requirement not met, but meets 25-50% of requirement
2 – requirement not met, but meets in excess of 50% of requirement
3 – requirement met
4 – requirement exceeded

Parameter 1: Operation in Spacecraft Environment
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Temperature	65–85°F (18-29°C)		4	4
Pressure	10.2–15.0 psia		4	4
Humidity	5–95% R.H.		4	4
Microgravity compatible		**Absolute Requirement**	*	*
Ability to perform in highly contaminated atmospheres		Resolution limits compound identification	3	3
Total Score			15	15

***No score given for absolute requirement.

Parameter 2: Instrument Characteristics
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Quantitation range	0.01–10 ppm	Concern about a gap between IMS and TCD	2	3
Analysis time	< 1 hr		3.5	4
Analytical cycle time	< 1.5 hr		4	4
Mass	22 kg		3	4
Volume	1.2 ft^3 (0.034 m^3)		3	4
Power	< 100 W/150 W peak	Question remains about peak power level	3.5	4
Total Score			19	23

Parameter 3: System Characteristics
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Maturity (WF = 2)	> 75% COTS		3*	4*
Resources (WF = 1)	1 + power & data	N_2 for the GC	3**	3**
Environmental impact (WF = 1)	Contaminants not released to atmosp.		3***	3***
Complexity (WF =2)	< 5 modules (heaters, GCs, detectors, etc., pneumatics)		2.5****	2.5****
Total Score			11.5	12.5

*Maturity: 100% COTS = 4, 75% COTS = 3, 50% COTS = 2, 25% COTS = 1, < 25% COTS = 0
**Resources: 0 resources = 4, 1 resource = 3, 2 resources = 2, > 2 resources = 0, exotic resource (i.e., LN_2) = disqualified
***Env.: No products released = 3, products released/not harmful = 2, released products harmful to crew/systems = 0
****Complexity: < 3 modules = 4, < 5 modules = 3, < 8 modules = 2, < 10 modules = 1, > 10 modules = 0

Parameter 4: Compounds
Weighting factor = 2

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
% Detectable Cat 1 compounds at specified limit	90%	Ammonia and formaldehyde not quantified	3	3
% Detectable Cat 2 and 3 compounds at specified limit	80%	Can see siloxanes	3.5	3.5
Specificity in spacecraft atmosphere	90% of Category 1 compound list	Bypass function would help GC issues	3	3
Specificity in spacecraft atmosphere	80% of Category 2 compound list		3.5	3.5
Accuracy (6 mo.)	± 30-50%	Potential for gap between IMS and TCD	2.5	3.5
Precision (over 1 mo. operation)	± 20%	Potential problems at end of range	3	4
Total Score			18.5	20.5

Parameter 5: Instrument Maintainability
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Calibration interval (quantitative purposes)	6 mo.		3	3.5
Maintenance interval: minor major	Every 6 mo. > 1 yr		3	3
ORUs and supplies	Every 6 mo. < 5 kg		4*	4*
Total Score			10	10.5

*ORU/supplies: > 6 mo./< 3 kg = 4, 6 mo./< 5 kg = 3, 6 mo./> 5 kg = 2, < 6 mo./< 5 kg = 1, < 6 mo./> 5 kg = 0

Technology Assessment Metric for JPL-Chutjian
Air Quality Panel: ISS Environmental Monitoring
Request for Information

Requirements Scale (except where noted)
0 – requirement not met
1 – requirement not met, but meets 25 -50% of requirement
2 – requirement not met, but meets in excess of 50% of requirement
3 – requirement met
4 – requirement exceeded

Parameter 1: Operation in Spacecraft Environment
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Temperature	65–85°F (18-29°C)	Concern about heat from turbo pump	3	3
Pressure	10.2–15.0 psia		4	4
Humidity	5–95% R.H.	No problem as long as no direct injection to MS	4	4
Microgravity compatible		**Absolute Requirement**	*	*
Ability to perform in highly contam-inated atmospheres		Question about potential to overload small trap	2.5	3
Total Score			13.5	14

***No score given for absolute requirement.**

Parameter 2: Instrument Characteristics
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Quantitation range	0.01–10 ppm		3	3
Analysis time	< 1 hr		4	4
Analytical cycle time	< 1.5 hr		4	4
Mass	22 kg		4	4
Volume	1.2 ft^3 (0.034 m^3)		4	4
Power	<100 W/150 W peak		4	4
Total Score			23	23

Parameter 3: System Characteristics
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Maturity (WF = 2)	> 75% COTS	No direct injection program Questions reproducibility w/Paul trap	2.5*	3.5*
Resources (WF = 1)	1 + power & data	Helium, vacuum, possibly N_2	2.5**	3**
Environmental impact (WF = 1)	Contaminants not released to atmosp.	? Concerns about using BTEX to calibrate spectral range ? Venting BTEX & helium are issues ? Helium may affect MCA on board	2***	3***
Complexity (WF =2)	< 5 modules (heaters, GCs, detectors, etc., pneumatics)		2.5****	2.5****
Total Score			9.5	12

*Maturity: 100% COTS = 4, 75% COTS = 3, 50% COTS = 2, 25% COTS = 1, <25% COTS = 0
**Resources: 0 resources = 4, 1 resource = 3, 2 resources = 2, > 2 resources = 0, exotic resource (i.e., LN_2) = disqualified
***Env.: No products released = 3, products released/not harmful = 2, released products harmful to crew/systems = 0
****Complexity: < 3 modules = 4, < 5 modules = 3, < 8 modules = 2, < 10 modules = 1, > 10 modules = 0

Parameter 4: Compounds
Weighting factor = 2

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
% Detectable Cat 1 compounds at specified limit	90%	Problems with ammonia and formaldehyde affect score	2.5	2.5
% Detectable Cat 2 and 3 compounds at specified limit	80%		3.5	4
Specificity in spacecraft atmosphere	90% of Category 1 compound list	Mixtures may cause a problem for direct inject MS devices	2.5	3
Specificity in spacecraft atmosphere	80% of Category 2 compound list	Mixtures may cause a problem for direct inject MS devices	2.5	3
Accuracy (6 mo.)	± 30–50%	Likelihood of frequent calibration of detectors/column	3	4
Precision (over 1 mo. operation)	± 20%	Questions about column stability	3	4
Total Score			17	20.5

Parameter 5: Instrument Maintainability
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Calibration interval (quantitative purposes)	6 mo.	Score affected by likelihood of frequent calibrations	2.5	2.5
Maintenance interval: minor major	Every 6 mo. >1 yr	Need for filament cleaning	3	3
ORUs and supplies	Every 6 mo. < 5 kg		4*	4*
Total Score			9.5	9.5

*ORU/Supplies: > 6 mo./< 3 kg = 4, 6 mo./< 5 kg = 3, 6 mo./> 5 kg = 2, < 6 mo./< 5 kg = 1, < 6 mo./> 5 kg = 0

Technology Assessment Metric for JPL-Houseman
Air Quality Panel: ISS Environmental Monitoring
Request for Information

Requirements Scale (except where noted)
0 – requirement not met
1 – requirement not met, but meets 25–50% of requirement
2 – requirement not met, but meets in excess of 50% of requirement
3 – requirement met
4 – requirement exceeded

Parameter 1: Operation in Spacecraft Environment
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Temperature	65–85°F (18-29°C)		3	3
Pressure	10.2–15.0 psia		4	4
Humidity	5–95% R.H.		4	4
Microgravity compatible		**Absolute Requirement**	*	*
Ability to perform in highly contaminated atmospheres		Concern about the unprotected inlet and the low sampling capacity	2	3
Total Score			13	14

***No score given for absolute requirement.

Parameter 2: Instrument Characteristics
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Quantitation range	0.01–10 ppm	Some dependency on GC separation	2	3
Analysis time	< 1 hr		4	4
Analytical cycle time	< 1.5 hr		4	4
Mass	22 kg		3	4
Volume	1.2 ft^3 (0.034 m^3)		2	3
Power	< 100 W/150 W peak		4	4
Total Score			19	22

Parameter 3: System Characteristics
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Maturity (WF = 2)	> 75% COTS	Need to get to higher mass range	2*	3*
Resources (WF = 1)	1 + power & data		3**	3**
Environmental impact (WF = 1)	Contaminants not released to atmosp.		3***	3***
Complexity (WF =2)	< 5 modules (heaters, GCs, detectors, etc., pneumatics)	Turbo pumps, power supply	3****	3****
Total Score			11	12

*Maturity: 100% COTS = 4, 75% COTS = 3, 50% COTS = 2, 25% COTS = 1, < 25% COTS = 0
**Resources: 0 resources = 4, 1 resource = 3, 2 resources = 2, > 2 resources = 0, exotic resource (i.e., LN_2) = disqualified
***Env.: No products released = 3, products released/not harmful = 2, released products harmful to crew/systems = 0
****Complexity: < 3 modules = 4, < 5 modules = 3, < 8 modules = 2, <10 modules = 1, > 10 modules = 0

Parameter 4: Compounds
Weighting factor = 2

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
% Detectable Cat 1 compounds at specified limit	90%		2.5	3
% Detectable Cat 2 and 3 compounds at specified limit	80%		3	3
Specificity in spacecraft atmosphere	90% of Category 1 compound list		3	3
Specificity in spacecraft atmosphere	80% of Category 2 compound list		3	3
Accuracy (6 mo.)	± 30-50%	Needs stable column	3	4
Precision (over 1 mo. operation)	± 20%		3	4
Total Score			17.5	20

Parameter 5: Instrument Maintainability
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Calibration interval (quantitative purposes)	6 mo.	There is some expectation of system drift	2.5	2.5
Maintenance interval: minor major	Every 6 mo. > 1 yr	Dual filament, ion source cleaning requirements	3	3
ORUs and Supplies	Every 6 mo. < 5 kg	Need for calibration gases and possible pump	3*	3.5*
Total Score			8.5	9

*ORU/Supplies: > 6 mo./< 3 kg = 4, 6 mo./< 5 kg = 3, 6 mo./> 5 kg = 2, < 6 mo./< 5 kg = 1, < 6 mo./> 5 kg = 0

Technology Assessment Metric for Star Instruments
Air Quality Panel: ISS Environmental Monitoring
Request for Information

Requirements Scale (except where noted)
0 – requirement not met
1 – requirement not met, but meets 25–50% of requirement
2 – requirement not met, but meets in excess of 50% of requirement
3 – requirement met
4 – requirement exceeded

Parameter 1: Operation in Spacecraft Environment
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Temperature	65–85°F (18-29°C)		4	4
Pressure	10.2–15.0 psia	PID may require different calibrations	2.5	3.5
Humidity	5–95% R.H.		4	4
Microgravity compatible		**Absolute Requirement**	*	*
Ability to perform in highly contaminated atmospheres		The small trap is an advantage from a cleanup standpoint	3	4
Total Score			13.5	15.5

***No score given for absolute requirement.**

Parameter 2: Instrument Characteristics
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Quantitation range	0.01–10 ppm	Strongly dependent on detectors, and no data were shown	2	4
Analysis time	< 1 hr		4	4
Analytical cycle time	< 1.5 hr		4	4
Mass	22 kg		4	4
Volume	1.2 ft^3 (0.034 m^3)		3	4
Power	< 100 W/150 W peak	The needed addition of detectors will also add power consumption	3	4
Total Score			20	24

Parameter 3: System Characteristics
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Maturity (WF = 2)	> 75% COTS	Question about what detector will be chosen	2.5*	4*
Resources (WF = 1)	1 + power & data	N_2 and argon possibly needed for plasma detector	2.5**	3**
Environmental impact (WF = 1)	Contaminants not released to atmosp.	Possible release and accumulation of argon	2.5***	3***
Complexity (WF =2)	< 5 modules (heaters, GCs, detectors, etc., pneumatics)	At least 6 modules, very complex	2.5****	2.5****
Total Score			10	12.5

*Maturity: 100% COTS = 4, 75% COTS = 3, 50% COTS = 2, 25% COTS = 1, < 25% COTS = 0
**Resources: 0 resources = 4, 1 resource = 3, 2 resources = 2, > 2 resources = 0, exotic resource (i.e., LN_2) = disqualified
***Env.: No products released = 3, products released/not harmful = 2, released products harmful to crew/systems = 0
****Complexity: < 3 modules = 4, < 5 modules = 3, < 8 modules = 2, < 10 modules = 1, > 10 modules = 0

Parameter 4: Compounds
Weighting factor = 2

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
% Detectable Cat 1 compounds at specified limit	90%	Depends on selected detectors and traps	2.5	3
% Detectable Cat 2 and 3 compounds at specified limit	80%		3	3.5
Specificity in spacecraft atmosphere	90% of Category 1 compound list	Mixture concerns	2.5	3.5
Specificity in spacecraft atmosphere	80% of Category 2 compound list	Mixture concerns	2.5	3.5
Accuracy (6 mo.)	± 30–50%		3	4
Precision (over 1 mo. operation)	± 20%	Will depend on calibration gases	3	4
Total Score			16.5	21.5

Parameter 5: Instrument Maintainability
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Calibration interval (quantitative purposes)	6 mo.	Possibly frequent because of the DiDD	2.5	2.5
Maintenance interval: minor major	Every 6 mo. > 1 yr	Possibility of DiDD electrode maintenance	2.5	3
ORUs and Supplies	Every 6 mo. < 5 kg	Need for calibration gases	3*	4*
Total Score			8	9.5

*ORU/Supplies: > 6 mo./< 3 kg = 4, 6 mo./< 5 kg = 3, 6 mo./> 5 kg = 2, < 6 mo./< 5 kg = 1, < 6 mo./> 5 kg = 0

Technology Assessment Metric for Boeing
Air Quality Panel: ISS Environmental Monitoring
Request for Information

Requirements Scale (except where noted)
0 – requirement not met
1 – requirement not met, but meets 25–50% of requirement
2 – requirement not met, but meets in excess of 50% of requirement
3 – requirement met
4 – requirement exceeded

Parameter 1: Operation in Spacecraft Environment
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Temperature	65–85°F (18-29°C)		3	3
Pressure	10.2–15.0 psia		4	4
Humidity	5–95% R.H.		4	4
Microgravity compatible		**Absolute Requirement**	*	*
Ability to perform in highly contaminated atmospheres			2.5	3
Total Score			13.5	14

***No score given for absolute requirement.**

Parameter 2: Instrument Characteristics
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Quantitation range	0.01–10 ppm		3	3.5
Analysis time	< 1 hr		4	4
Analytical cycle time	< 1.5 hr		4	4
Mass	22 kg		2	3.5
Volume	1.2 ft^3 (0.034 m^3)		1.5	3
Power	< 100 W/150 W peak		1	3
Total Score			15.5	21

Parameter 3: System Characteristics
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Maturity (WF = 2)	> 75% COTS	Will depend on what is actually selected	2.5*	3*
Resources (WF = 1)	1 + power & data		2.5**	3**
Environmental impact (WF = 1)	Contaminants not released to atmosp.	Questions about calibration gases	3***	3***
Complexity (WF =2)	< 5 modules (heaters, GCs, detectors, etc., pneumatics)		2.5****	2.5****
Total Score			10.5	11.5

*Maturity: 100% COTS = 4, 75% COTS = 3, 50% COTS = 2, 25% COTS = 1, < 25% COTS = 0
**Resources: 0 resources = 4, 1 resource = 3, 2 resources = 2, > 2 resources = 0, exotic resource (i.e., LN_2) = disqualified
***Env.: No products released = 3, products released/not harmful = 2, released products harmful to crew/systems = 0
****Complexity: < 3 modules = 4, < 5 modules = 3, < 8 modules = 2, < 10 modules = 1, > 10 modules = 0

Parameter 4: Compounds
Weighting factor = 2

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
% Detectable Cat 1 compounds at specified limit	90%		2.5	3.5
% Detectable Cat 2 and 3 compounds at specified limit	80%		3.5	4
Specificity in spacecraft atmosphere	90% of Category 1 compound list		2.5	3.5
Specificity in spacecraft atmosphere	80% of Category 2 compound list		3	4
Accuracy (6 mo.)	± 30-50%		3	4
Precision (over 1 mo. operation)	± 20%		3	3
Total Score			17.5	22

Parameter 5: Instrument Maintainability
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Calibration interval (quantitative purposes)	6 mo.	Possibility of frequent calibration	2.5	3
Maintenance interval: minor major	Every 6 mo. >1 yr.		3	3
ORUs and Supplies	Every 6 mo. < 5 kg		3*	3*
Total Score			8.5	9

*ORU/Supplies: > 6 mo./< 3 kg = 4, 6 mo./< 5 kg = 3, 6 mo./> 5 kg = 2, < 6 mo./< 5 kg = 1, < 6 mo./> 5 kg = 0

Technology Assessment Metric for Bruker
Air Quality Panel: ISS Environmental Monitoring
Request for Information

Requirements Scale (except where noted)
0 – requirement not met
1 – requirement not met, but meets 25–50% of requirement
2 – requirement not met, but meets in excess of 50% of requirement
3 – requirement met
4 – requirement exceeded

Parameter 1: Operation in Spacecraft Environment
Weighting factor = 1

Attribute	**Mission Requirement**	**System Performance**	**Score (0–4) Demonstrated**	**Score (0–4) Potential**
Temperature	65–85°F (18-29°C)		4	4
Pressure	10.2–15.0 psia		4	4
Humidity	5–95% R.H.	Concern about PID; potential score anticipates change	3	4
Microgravity compatible		**Absolute Requirement**	*****	*****
Ability to perform in highly contaminated atmospheres		? Concern about ability to detect unknowns, and the potential for confounding of results ? Potential score based on possibility of a GC-IMS interface and recognition that a variety of detectors may improve capabilities to deal with unknowns	1	3
Total Score			12	15

*****No score given for absolute requirement.

Parameter 2: Instrument Characteristics
Weighting factor = 1

Attribute	**Mission Requirement**	**System Performance**	**Score (0–4) Demonstrated**	**Score (0–4) Potential**
Quantitation range	0.01–10 ppm	Concern about general lack of sensitivity; GDA and the variety of detectors may help mitigate concerns, although performance still needs to be demonstrated	2	3
Analysis time	< 1 hr		4	4
Analytical cycle time	< 1.5 hr		4	4
Mass	22 kg		4	4
Volume	1.2 ft^3 (0.034 m^3)		3	4
Power	< 100 W/150 W peak		4	4
Total Score			21	23

Parameter 3: System Characteristics
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Maturity (WF = 2)	> 75% COTS	Custom library and training sets needed	2*	3*
Resources (WF = 1)	1 + power & data	Needs both N_2 (possible use of filtered air) and cleanup	3**	3**
Environmental impact (WF = 1)	Contaminants not released to atmosp.		3***	3***
Complexity (WF = 2)	< 5 modules (heaters, GCs, detectors, etc., pneumatics)	More than nine modules, but still only partial capability	2****	2****
Total Score			10	11

*Maturity: 100% COTS = 4, 75% COTS = 3, 50% COTS = 2, 25% COTS = 1, < 25% COTS = 0
**Resources: 0 resources = 4, 1 resource = 3, 2 resources = 2, > 2 resources = 0, exotic resource (i.e., LN_2) = disqualified
***Env.: No products released = 3, products released/not harmful = 2, released products harmful to crew/systems = 0
****Complexity: < 3 modules = 4, < 5 modules = 3, < 8 modules = 2, < 10 modules = 1, > 10 modules = 0

Parameter 4: Compounds
Weighting factor = 2

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
% Detectable Cat 1 compounds at specified limit	90%	Somewhat unknown	2.5	3
% Detectable Cat 2 and 3 compounds at specified limit	80%		2.5	3
Specificity in spacecraft atmosphere	90% of category 1 compound list	Use N_2 or air	2.5	3
Specificity in spacecraft atmosphere	80% of category 2 compound list		2.5	3
Accuracy (6 mo.)	± 30–50%	? Need demonstration ? Concern about oxide sensors, potential for PID windows degrade ? IMS membrane requires only periodic use	2	2.5
Precision (over 1 mo. operation)	± 20%		1	2.5
Total Score			13	17

Parameter 5: Instrument Maintainability
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Calibration interval (quanti-tative purposes)	6 mo.		1	2
Maintenance interval: minor major	Every 6 mo. > 1 yr		3	3
ORUs and Supplies	Every 6 mo. < 5 kg		4*	4*
Total Score Parameter Score			8	9

*ORU/Supplies: > 6 mo./< 3 kg = 4, 6 mo./< 5 kg = 3, 6 mo./> 5 kg = 2, < 6 mo./< 5 kg = 1, < 6 mo./> 5 kg = 0

Technology Assessment Metric for Space Dynamics
Air Quality Panel: ISS Environmental Monitoring
Request for Information

Requirements Scale (except where noted)
0 – requirement not met
1 – requirement not met, but meets 25–50% of requirement
2 – requirement not met, but meets in excess of 50% of requirement
3 – requirement met
4 – requirement exceeded

Parameter 1: Operation in Spacecraft Environment
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Temperature	65–85°F (18-29°C)		0	4
Pressure	10.2–15.0 psia		0	4
Humidity	5–95% R.H.	Dryer option considered in the potential score	0	3
Microgravity compatible		**Absolute Requirement**	*	*
Ability to perform in highly contaminated atmospheres		FTIR feedback is an issue	0	3
Total Score			0	14

*****No score given for absolute requirement.

Parameter 2: Instrument Characteristics
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Quantitation range	0.01–10 ppm		0	3
Analysis time	< 1 hr		0	4
Analytical cycle time	< 1.5 hr		0	4
Mass	22 kg		0	2.5
Volume	1.2 ft^3 (0.034 m^3)		0	2.5
Power	< 100 W/150 W peak	Sterling cooler	0	2.5
Total Score			0	18.5

Parameter 3: System Characteristics
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Maturity (WF = 2)	> 75% COTS		0*	?*
Resources (WF = 1)	1 + power & data		0**	3**
Environmental impact (WF = 1)	Contaminants not released to atmosp.		0***	3***
Complexity (WF =2)	< 5 modules (heaters, GCs, detectors, etc., pneumatics)	Concerns about there being close to 10 modules	0****	1****
Total Score			0	?

*Maturity: 100% COTS = 4, 75% COTS = 3, 50% COTS = 2, 25% COTS = 1, < 25% COTS = 0
**Resources: 0 resources = 4, 1 resource = 3, 2 resources = 2, > 2 resources = 0, exotic resource (i.e., LN_2) = disqualified
***Env.: No products released = 3, products released/not harmful = 2, released products harmful to crew/systems = 0
****Complexity: < 3 modules = 4, < 5 modules = 3, < 8 modules = 2, < 10 modules = 1, > 10 modules = 0

Parameter 4: Compounds
Weighting factor = 2

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
% Detectable Cat 1 compounds at specified limit	90%		0	3
% Detectable Cat 2 and 3 compounds at specified limit	80%		0	3
Specificity in spacecraft atmosphere	90% of Category 1 compound list		0	3
Specificity in spacecraft atmosphere	80% of Category 2 compound list		0	3
Accuracy (6 mo.)	± 30–50%		0	3
Precision (over 1 mo. operation)	± 20%		0	3
Total Score			0	15

Parameter 5: Instrument Maintainability
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Calibration interval (quantitative purposes)	6 mo.	Concern about GC calibration requirements	0	3
Maintenance interval: minor major	Every 6 mo. > 1 yr		0	3
ORUs and Supplies	Every 6 mo. < 5 kg		0*	4*
Total Score			0	10

*ORU/Supplies: > 6 mo./< 3 kg = 4, 6 mo./< 5 kg = 3, 6 mo./> 5 kg = 2, < 6 mo./< 5 kg = 1, < 6 mo./> 5 kg = 0

Technology Assessment Metric for OI-Analytical Air Quality Panel: ISS Environmental Monitoring Request for Information

Requirements Scale (except where noted)
0 – requirement not met
1 – requirement not met, but meets 25–50% of requirement
2 – requirement not met, but meets in excess of 50% of requirement
3 – requirement met
4 – requirement exceeded

Parameter 1: Operation in Spacecraft Environment
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Temperature	65–85°F (18-29°C)		0	4
Pressure	10.2–15.0 psia		0	4
Humidity	5–95% R.H.	Potential for confounding	0	3
Microgravity compatible		**Absolute Requirement**	*	*
Ability to perform in highly contaminated atmospheres			0	2.5
Total Score			0	13.5

*No score given for absolute requirement.

Parameter 2: Instrument Characteristics
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Quantitation range	0.01–10 ppm	Questions about size of sample, detectors (MSD)	0	?
Analysis time	< 1 hr		0	4
Analytical cycle time	< 1.5 hr		0	4
Mass	22 kg	Turbo pump and MSD consideration affect score	0	3
Volume	1.2 ft^3 (0.034 m^3)		0	3
Power	< 100 W/150 W peak		0	2.5
Total Score			0	?

Parameter 3: System Characteristics
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Maturity (WF = 2)	> 75% COTS		0*	4*
Resources (WF = 1)	1 + power & data	Vacuum and N_2	0**	2**
Environmental impact (WF = 1)	Contaminants not released to atmosp.		0***	3***
Complexity (WF =2)	< 5 modules (heaters, GCs, detectors, etc., pneumatics)		0****	1.5****
Total Score			0	10.5

*Maturity: 100% COTS = 4, 75% COTS = 3, 50% COTS = 2, 25% COTS = 1, < 25% COTS = 0
**Resources: 0 resources = 4, 1 resource = 3, 2 resources = 2, > 2 resources = 0, exotic resource (i.e., LN_2) = disqualified
***Env.: No products released = 3, products released/not harmful = 2, released products harmful to crew/systems = 0
****Complexity: < 3 modules = 4, < 5 modules = 3, < 8 modules = 2, < 10 modules = 1, > 10 modules = 0

Parameter 4: Compounds
Weighting factor = 2

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
% Detectable Cat 1 compounds at specified limit	90%	Questions about detectors (MSD)	0	3.5
% Detectable Cat 2 and 3 compounds at specified limit	80%		0	3.5
Specificity in spacecraft atmosphere	90% of Category 1 compound list		0	3.5
Specificity in spacecraft atmosphere	80% of Category 2 compound list		0	3.5
Accuracy (6 mo.)	± 30–50%		0	4
Precision (over 1 mo. operation)	± 20%		0	4
Total Score			0	22

Parameter 5: Instrument Maintainability
Weighting factor = 1

Attribute	Mission Requirement	System Performance	Score (0–4) Demonstrated	Score (0–4) Potential
Calibration interval (quantitative purposes)	6 mo.	Possibility of sorbant retentions, GC calibration issues	0	2
Maintenance interval: minor major	Every 6 mo. >1 yr.	Concern about possible heater failures	0	2
ORUs and Supplies	Every 6 mo. < 5 kg		0*	4*
Total Score			0	8

* ORU/Supplies: > 6 mo./< 3 kg = 4, 6 mo./<5 kg = 3, 6 mo./> 5 kg = 2, < 6 mo./< 5 kg = 1, < 6 mo./> 5 kg = 0

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.			
1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE July 2004	3. REPORT TYPE AND DATES COVERED NASA Technical Memorandum	
4. TITLE AND SUBTITLE Air Quality Monitoring Report: A Review of Responses to the NASA Request for Information on Trace Contaminant Monitoring			5. FUNDING NUMBERS
6. AUTHOR(S)			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) International Space Station Program Office; Advanced Human Support Technology; JSC Toxicology Group			8. PERFORMING ORGANIZATION REPORT NUMBERS S-935
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001			10. SPONSORING/MONITORING AGENCY REPORT NUMBER TM-2004-213144
11. SUPPLEMENTARY NOTES			
12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified/Unlimited Available from the NASA Center for AeroSpace Information (CASI) 7121 Standard Hanover, MD 21076-1320 Category: 54			12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The ability to monitor the atmosphere of the International Space Station (ISS) is critical to managing health risks and, ultimately, to mission success. Air monitoring in the space environment poses numerous technical challenges. Addressing these challenges is not new to NASA, which has significant experience with spacecraft air pollutant monitoring. Nevertheless it is important for NASA to build on lessons learned and to continue to seek out new approaches that can approve the Agency's ability to assess spacecraft habitability. To this end, a Request for Information (RFI) for the ISS on-board environmental monitoring system was released on August 9, 2003. Its purpose was to identify next-generation environmental monitoring systems with demonstrated ability or potential to meet defined requirements for systems to evaluate air and water quality on board the ISS. This report summarizes the submission and analysis of proposed solutions designed to improve the functionality of the existing volatile organic analyzer (VOA), which is responsible for analyzing a wide range of volatile organic compounds that may be present in the Station atmosphere. Experience with the existing ISS VOA has been varied, so NASA is using this RFI to investigate new technologies that may improve on existing capabilities.

14. SUBJECT TERMS		15. NUMBER OF PAGES	16. PRICE CODE
environments; in-flight monitoring; atmospheric composition; organic compounds; aerospace systems engineering; systems management; International Space Station		54	

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unlimited	Unlimited

Standard Form 298 (Rev Feb 89) (MS Word Mar 97) NSN 7540-01-280-5500
Prescribed by ANSI Std. 239-18
298-102